Computer Art: A Visual Model for the Modular Pictures of Manuel Barbadillo
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# COMPUTER ART: A VISUAL MODEL FOR THE MODULAR PICTURES OF MANUEL BARBADILLO

**Michael Thompson***

**Abstract**—*From 1964 to 1968, Manuel Barbadillo based many of his pictures on a single black and white square module. Sixteen different forms (structural elements) can be generated from this module by rotation, mirror image and by interchanging black and white. Any of these structural elements can be used in each position of a 4 × 4 grid to construct a picture.*

*Areas of the same colour in adjacent structural elements coalesce and lead the eye freely about the picture. In addition to this aspect of the picture, the artist used strong symmetry, which gives 'liveliness' to it. The ideas involved are very vague and the main purpose of this paper is to demonstrate how to render them amenable to computer programming.*

*Firstly, the author subjectively distinguishes 'tracking' movement and 'skipping' movement of the eyes and describes them in detail. Next, these concepts are 'temporarily closed' by definitions. These definitions define a subjective visual model but cannot define the real visual qualities of Barbadillo's pictures. They permit numerical analysis. Eight test pictures of 2 × 2 elements are presented with numerical results that seem plausible. It is hoped that the incorporation of this subjective visual model into a computer programme may enable the generation of pictures controlled by automatic processes of selectivity.*

## I. STRUCTURAL ELEMENTS

Computers are sometimes used in art to aid in arranging compositions made up of the repeated use of one or more modules [1–4]. The modules used in this manner by the Spanish artist Manuel Barbadillo are shown in Fig. 1. A typical example of his pictures is given in Fig. 2. Modules (a) and (b) in Fig. 1 appear most often in his works; each may be presented in sixteen different ways given by *rotation*, *mirror image* and *interchange of black and white*. I refer to each of these sixteen ways as a *structural element*. The painting shown in Fig. 2 is a 4 × 4 grid made up of 16 structural elements of eight different kinds.

Barbadillo has noted the following characteristics of pictures made from an array of structural elements:

a. The number of pictures that one can produce from a few structural elements is enormous but, comparatively, the number that is pleasing is very small.

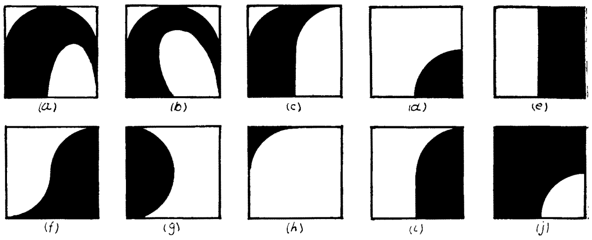


*Fig. 1. Modules employed in pictures by Manuel Barbadillo.*

b. When colours match along the common edge of two structural elements, new forms are produced. The fusing of forms into extended black and white areas sometimes leads to a feeling of a white form on a black background or *vice versa*.

c. A group of, say, 2 × 2 structural elements can be used as one element. In Fig. 2, the top left-hand quadrant may be regarded as a *structural group* that generated: the bottom left-hand quadrant by *repetition*; the top-right-hand quadrant by *point reflection* about the point in

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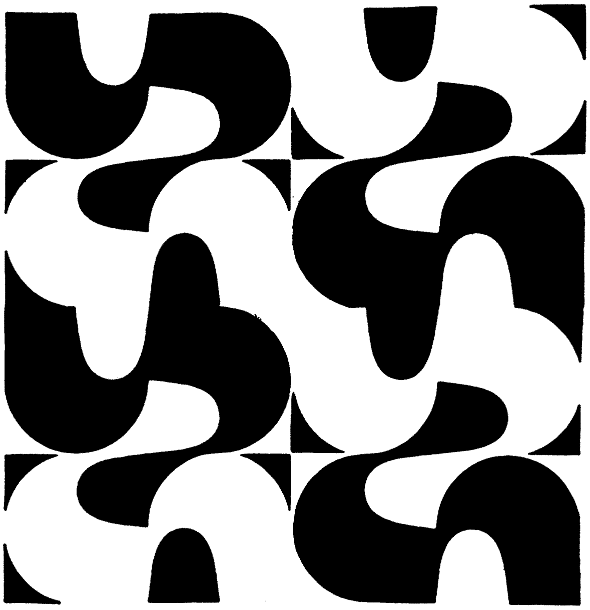

*Fig. 2. Manuel Barbadillo, 'Modular painting,* 1966', *acrylic paint on four equal canvasses,* 81 × 81 *cm, mounted together to give total size of* 162 × 162 cm.

the centre of the common boundary between the two quadrants; and the bottom right-hand quadrant by a point reflection about the centre point of the picture. In addition, the top right-hand quadrant may be regarded as being subject to a point reflection about the centre of the picture, so as to generate the bottom left-hand quadrant.

d. The proper joining of edges of structural elements is critical and often extremely difficult. (I have written a computer programme for performing edge matching [5].)
e. The angle at which a form meets that of an adjoining structural element may be important in giving a feeling of rhythm. Poor matching may often be used to accomplish this effect.
f. Pleasing relationships can be obtained by the use of repetition, point reflection, mirror image, rotation and colour reversal. These have been utilized in computer art programmes [6,7].

## II. SUBJECTIVE DECISIONS AND THE COMPUTER

Most artists who use computers for graphic works make the decisions on subjective concepts themselves, consciously or subconsciously, and then use the computer as an aid in generating the final pictures. My interests are rather different. I wish to learn how to incorporate in computer programmes a capacity for making some of the subjective decisions. The difficulty one faces is that subjective concepts are usually described in terms of *open concepts* [8] and, therefore, there is a lack of sufficient and necessary definitions for them. The mathematics in a computer programme is necessarily precisely defined and, consequently, capable of treating *closed concepts* only.

Typical open concepts that concern artists when making graphic works are: *depth cue, form, 'movement', 'tension', sensation of saturation* and *balance*. In order to incorporate such notions in computer programmes, it is proposed to specify a *subjective visual model* in which the definitions of subjective concepts are 'temporarily closed'. Such a model will incorporate some of the viewer's subjective notions as to what happens when he, personally, views the picture. Naturally, he cannot *know* the physiological processes taking place within him but, as to his appreciation of the picture, his notions on what he experiences are relevant. If some of these subjective notions can be described (approximated) in a 'temporarily closed' manner, then they are amenable to computer programming. A computer programme incorporating a model of these concepts should be able to generate pictures that will give rise to those very experiences that have been 'modelled'.

## III. THE SUBJECTIVE VISUAL MODEL

The eye movements of a viewer are, more or less, dictated by a picture. The stimuli of the picture channel the eyes along fairly well defined paths and, although they can visit any part of the picture surface, the most important paths can be identified and represented graphically. Numerous tests of the eye movements of picture viewers have been carried out and reported in the literature of experimental psychology [9, 10].

To utilize a digital computer, it is necessary to restate a problem in terms of numbers. How can one represent with only a few numbers the path followed by a swiftly moving eye? I used a *network*, a simple example of which is shown in Fig. 3. The numbered circles are called *nodes*. The viewer's attention is supposed to move between these nodes along the *arcs*. This network does not explain why the viewer's attention does this, e.g. why it travels between nodes 2 and 3 but not nodes 2 and 5. The

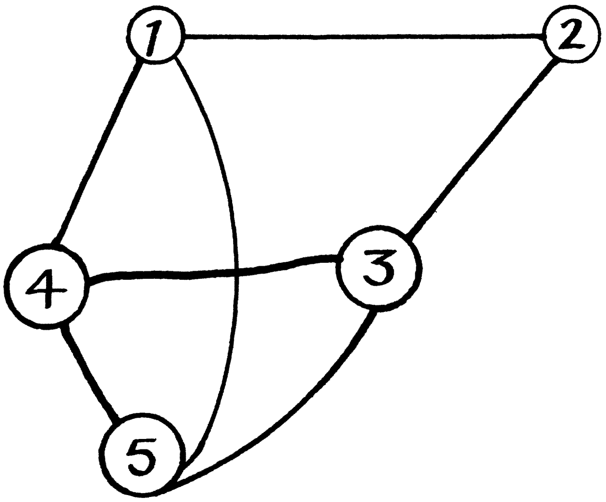


*Fig. 3. An example of a network.*

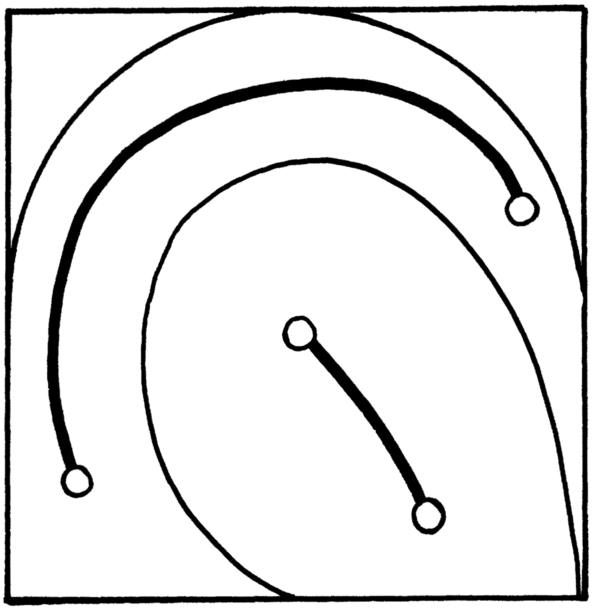

*Fig.* 4. *Module represented by four nodes and two arcs* (cf. Fig. 1 (b) ).

network merely states that this is what happens. It represents a closed definition of the situation and, although the definition may be changed at will, it provides the kind of precise material that a computer can handle.

The next questions to answer are: where on a picture surface do we put the nodes and how do we decide which pair of nodes involve an eye movement? Well, this is art, not science; I put them just where I liked. I did not engage 'twelve naive observers' for statistical testing with questionnaires but used rather my intuition backed by a great deal of study of modular compositions with my own eyes. I have found that most modules can be represented easily by about six nodes and around a dozen arcs but, in this paper, I have chosen a module that can quite usefully be represented by only four nodes and two arcs. How this is done is shown in Fig. 4.

I shall now describe the more obvious types of eye movement that I call *tracking* and present a very simple model for eventual computer application. The reader may discover that an important type of eye movement is omitted. This type, which I call *skipping*, will be described later in conjunction with another simple model.

## IV. THE PHENOMENON OF TRACKING

Tracking is experienced when the eyes seem to be guided by elements of the picture. It appears to be a continuous smooth movement but studies [9, 10] have shown the opposite. The eyes move in a series of incredibly fast jumps or jerks, called *saccades*, during which they are effectively blind. Between the saccades, the eyes look at particular points on the picture surface, called *fixation points*. Evidently, the images of these points fall upon the most sensitive part of the retina. The saccades are so fast that 95% of the viewing time is spent with the eyes almost motionless. This means that tracking movement is an illusion. The eyes, in fact, look at a series of points on the picture surface, which are possibly the same as those to which the mind is attending [9].

I consider that a network is a plausible model, for the arcs might represent saccades and the nodes fixation points. In a model for tracking, however, the arcs may be thought of as paths along which I have found my attention tends to move but no information is supplied by them as to the direction of movement of the eyes along them. When direction is not stated, the network is usually termed an *undirected graph* or just *graph* and the arcs are called *edges*. More detailed models use networks in which the direction of movement along the arcs is stated; they are usually termed *directed graphs*. Reference 10 is a simple introduction to networks; reference 12 is more advanced. Applications by Anthony Hill and by Frank Harary of graph theory to art can be found in previous issues of *Leonardo* [13, 14].

## V. SUBJECTIVE VISUAL MODEL FOR TRACKING

Here are the main rules for a very simple subjective model to describe the tracking movement, e.g. when looking at a 2 × 2 modular picture by Barbadillo (Fig. 5(a)–5(h) ) built from the module shown in Fig. 1(b):

1. Each structural element is represented by two arcs, one in the lobe, having an *arc value* of 2, and one in the curving area surrounding the lobe, having an arc value of 3 (Fig. 4).
2. One may connect a pair of the nodes in adjacent structural elements with a *connecting arc*. This may be done only if:
   (a) the whole length of the connecting arc lies in the same *colour zone* (i.e. a continuous area of a single colour) and the two ends of the arcs being connected and the connecting arc itself all lie on a smooth line that is nearly straight. Such a connecting arc is given an arc value of 2. (This rule emphasizes continuity in colour and in direction, which encourages tracking.)
   (b) either the whole length of the connecting arc lies in the same colour zone but the two ends of the arcs to be connected are at such angles that the connecting arc must contain a sharp bend—or the connecting arc crosses one or more boundaries between colour zones but the connecting arc and the arcs to be connected do lie on a smooth line that is nearly straight. In either of these two cases, the connecting arc is given an arc value of 1. No other connection may be made.
3. When all permitted connecting arcs have been put into the picture, we have one or more *connected networks*. Each connected network is given a score obtained by multiplying together all the values of the arcs that comprise

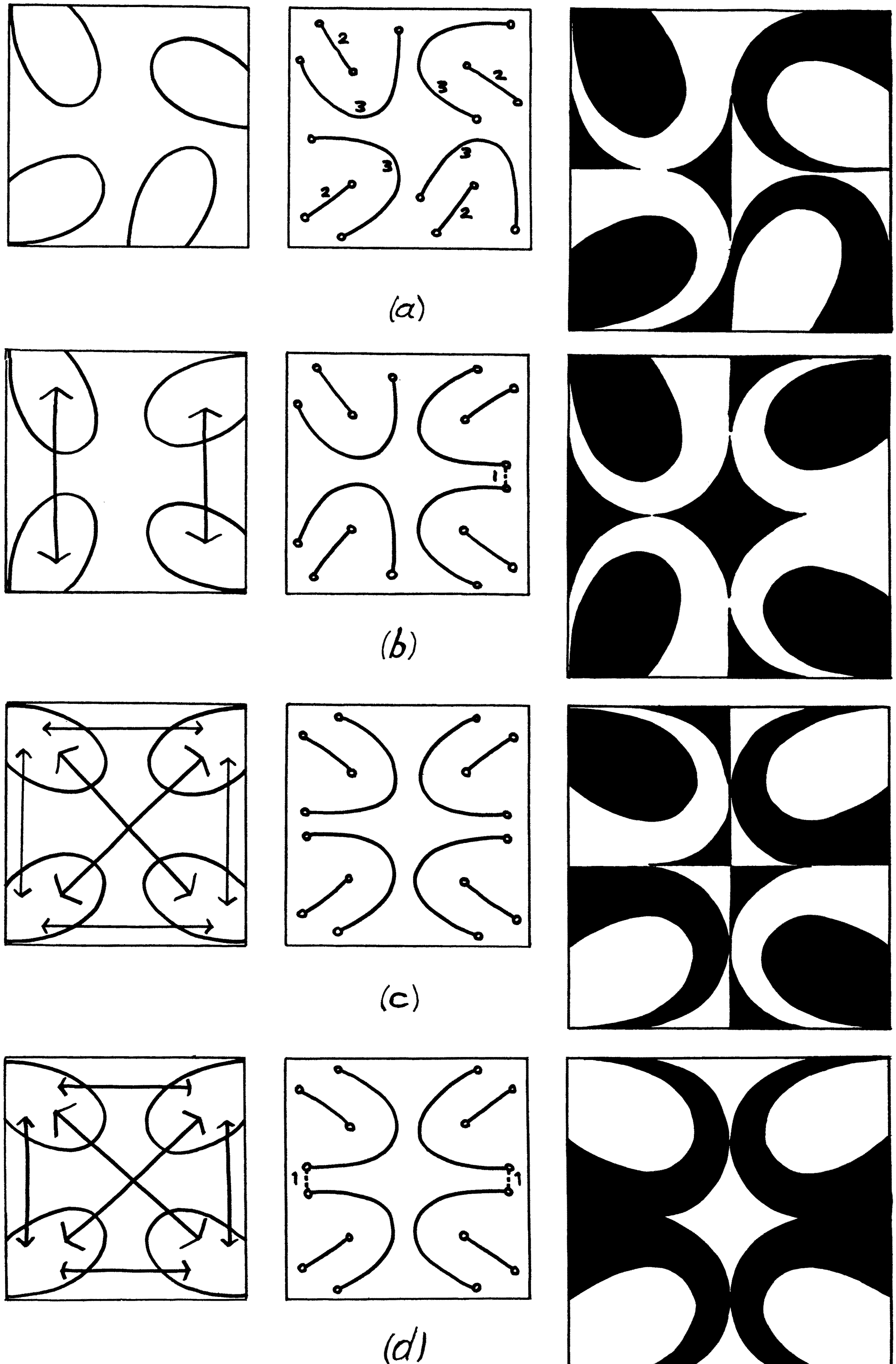


*Fig. 5. Eight modular pictures using the module of Manuel Barbadillo shown in Figure 1 (b). For each of them is shown a diagrammatic analysis of tracking (centre) and of skipping (on the left). (Fig. 5(e) to 5(h) on opposite page.)*

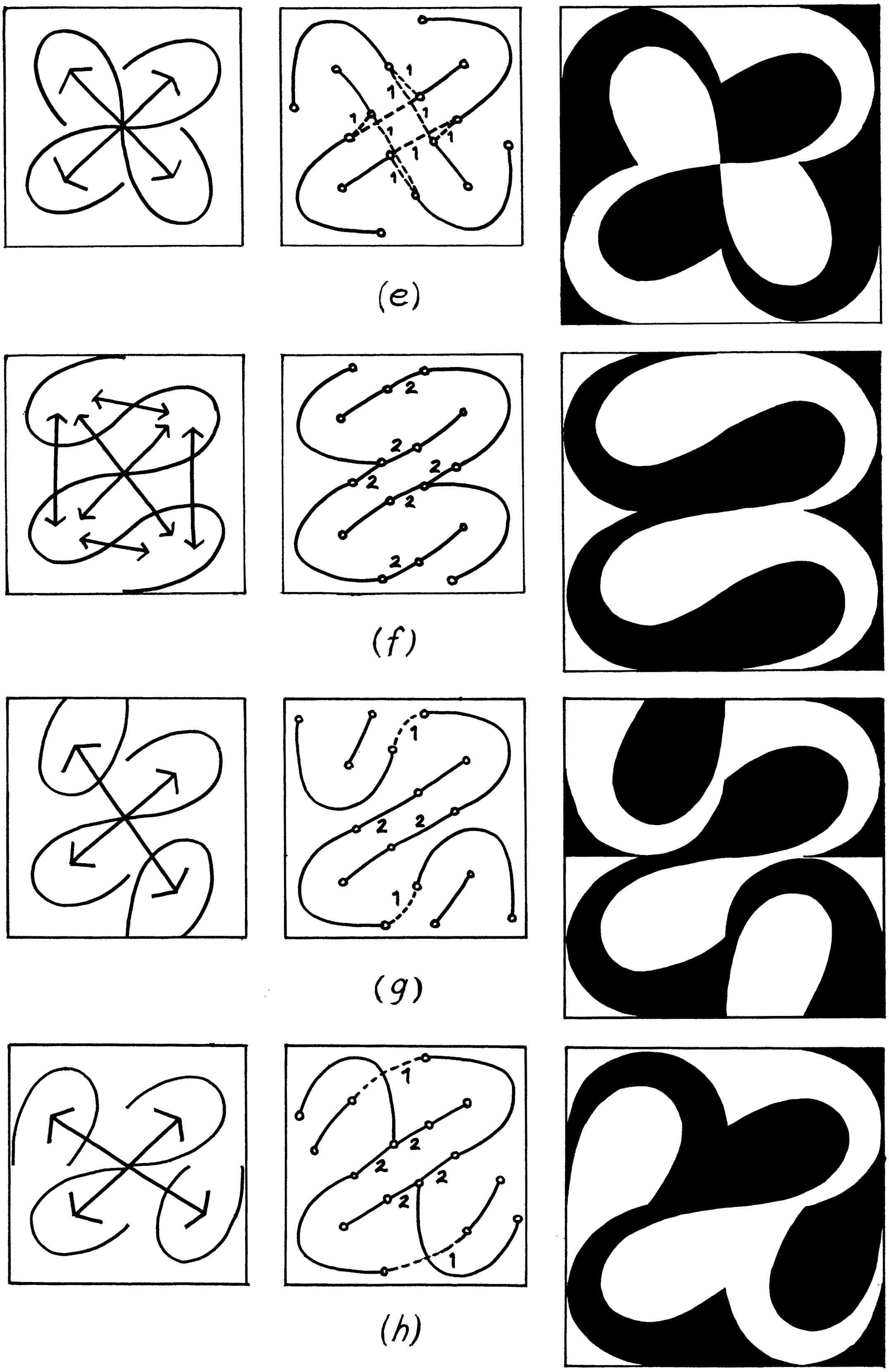


*Fig.* 5(*e*)–5(*h*)

it. An arc value of 1 contributes nothing to the product, yet it may link other arcs of value greater than one, which will themselves contribute. This is the reason why I have assigned a value of 1 to the arcs that represent parts of a picture that do not stimulate movement but link features that do stimulate. Where there are no arcs, arcs having an arc value of zero can be shown for the purposes of programming. The scores obtained from each connected network are added together to give a score for the whole picture. It is proposed that this score represents the content of tracking movement in the picture. This rule provides for the interdependence of different arcs along a single tracking route.

These rules are almost closed, therefore, a computer application may be possible. However, as they stand, it is not feasible to specify a computer programme to compute tracking scores without further definition. Clearly, 'nearly straight line' needs to be defined better. However, I was able to calculate 'by hand' the tracking scores in Table 1 for Figure 5(a)–5(h).

TABLE 1. TRACKING SCORES (cf. Fig. 5(a)–5(h) ).

| Figure number | For each type of *connected network*: Structure | Value | Frequency | Total | Total for picture |
|---|---|---|---|---|---|
| 5a | 3 | 3 | 4 | 12 | |
| | 2 | 2 | 4 | 8 | 20 |
| 5b | 3 | 3 | 2 | 6 | |
| | 2 | 2 | 4 | 8 | |
| | 3, 1, 3 | 9 | 1 | 9 | 23 |
| 5c | 3 | 3 | 4 | 12 | |
| | 2 | 2 | 4 | 8 | 20 |
| 5d | 2 | 2 | 4 | 8 | |
| | 3, 1, 3 | 9 | 2 | 18 | 26 |
| 5e | 3, 1, 2, 1, 3, 1, 2, 1, 3, 1, 2, 1, 3, 1, 2, 1 | 1296 | 1 | 1296 | 1296 |
| 5f | 2, 2, 3, 2, 2, 2, 3 | 288 | 2 | 576 | 576 |
| 5g | 3, 1, 3, 2, 2 | 36 | 2 | 72 | |
| | 2 | 2 | 2 | 4 | 76 |
| 5h | 3, 2, 2, 2, 3, 1, 2 | 144 | 2 | 288 | 288 |

## VI. THE PHENOMENON OF SKIPPING

Barbadillo often uses the term 'rhythm' in connection with his pictures. For instance, he wrote to me in 1971: 'I very strongly believe rhythm to be the main, the meaningful element of a painting, whether it is an abstract or figurative one.' Tracking movement did not provide a sufficient explanation of this, especially for certain pictures with little tracking movement. To deal with this, I developed the concept of *skipping* movement of the eyes.

Skipping movement is a transference of the observer's attention from one part of the picture to another. Subjectively, the process seems to be that the shape of a part of a coloured area is perceived and held in the observer's memory as a 'perceived object'. Sometimes the eyes seem to move without interruption in a straight line between two such 'perceived objects' for purposes of comparison. These lines are sketched in Fig. 5(a)–5(h) in the diagrammatic representation of skipping movement, which is the left-hand diagram of each set of three. Skipping movement is possibly a search for symmetry that will enable the viewer by perception to more easily store information in his mind.

The following pairs or classes invite skipping:

1. Repeated coloured areas.
2. A coloured area and its mirror image.
3. A coloured area and its point reflection.
4. A coloured area and a second coloured area that looks similar to but not exactly like the repetition or the mirror image or the point reflection of the first one.

It should be noted that the first three pairs are geometrically identified. The simple subjective visual model presented below in Part VII omits class 4 but classes 1, 2 and 3 are assigned numerical values that are chosen to conform to the writer's subjective judgments.

The reason for omitting class 4 from the model at this stage is that the definitions involved are very difficult to close. Consider, for instance, Fig. 5(a). It has no geometric symmetry but it is visually sufficiently symmetric for the viewer to want to try to understand it. The viewer attempts to simplify the picture by establishing symmetry. This accounts for most of the eye movements. I do not include this predominantly conscious searching in the class of skipping movements.

Skipping movements are enhanced by the following features:

1. Areas of the same colour.
2. Coloured areas emphasized by strong tracking.
3. Coloured areas isolated by the picture edge.
4. Coloured areas lying on the diagonals of the picture.
5. The line of skipping being vertical in the picture plane.
6. The axes of the coloured areas lying on the line of skipping.

Only the first three enhancing features in the above list are included in the simple model. The reason for this is merely that the other three became clear to me whilst I was carrying out studies on the model and I do not yet know how to incorporate them. Another reason is that simple calculations can be made without a computer. A more complex model would introduce much more difficult calculations, necessitating computer use.

As with the model for tracking, I have not fully closed the definitions for skipping. The enhancing feature, 'coloured areas emphasized by strong tracking', is particularly difficult to treat. We could say, for instance, referring to the tracking model, that if a certain score is exceeded, then tracking is 'strong' and we presume that skipping has been enhanced. This problem has been ignored for the present and I have made the decisions intuitively.

The numerical values for skipping are added, not multiplied. I consider that each instance of skipping is independent of the others.

## VII. SUBJECTIVE VISUAL MODEL FOR SKIPPING

I shall now define a simple subjective visual model that describes the skipping movement, as follows:

1. The skipping takes place between the lobes in pairs of structural elements (Fig. 5(a)–5(h) ).
2. The score accorded to each pair of lobes depends partly on the presence of any of the following relationships:
   A. The lobes are mirror images of each other across the common edge of a pair of adjacent structural elements.
   B. The lobes are repetitions of each other.
   C. The lobes are point reflections of each other across the centre of the picture.
   D. The lobes are point reflections of each other across the mid-point of the common edge of the structural elements containing them.

   These are the four basic relationships (Table 2). Their occurrence in the pictures in Fig. 5(a)–5(h) is recorded in Table 3 under the heading 'Relationship: Type'.
3. The score accorded to each pair of lobes depends also on the existence of the following enhancing features (cf. Table 2):
   P. Both lobes are the same colour.
   Q. Both lobes are emphasized by 'strong tracking'.
   R. Both lobes are isolated by the picture edge.

   Their occurrence in the pictures in Fig. 5(a)–5(h) is recorded in Table 3.
4. The values are totalled for each picture.

## VIII. RESULTS OF CALCULATIONS

The presentation of results here is superficially similar to a scientific paper in which measurements are published. Here, however, the link between the scores (totals) for tracking and skipping movement (Tables 1 and 3) and the eye movement analysis (Fig. 5(a)–5(h)) are subjective and personal matters. It would be equally possible for a qualified viewer to rank these pictures in a different order from mine for both tracking content and skipping content but I would hope for some similarity in ranking.

TABLE 3. SKIPPING SCORES (cf. FIG. 5(a)–5(h) ).

| | For each type of skipping movement | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Relationship: | | | | | | | |
| | | Enhancing features | | | | | | |
| Figure number | Type | P | Q | R | Score | Fre-quency | Total | Total for the picture |
| 5a | None | | | | 0 | 0 | 0 | 0 |
| 5b | A | Yes | No | Yes | 4 | 2 | 8 | 8 |
| 5c | A | No | No | Yes | 2 | 4 | 8 | |
| | C | Yes | No | Yes | 5 | 2 | 10 | 18 |
| 5d | A | Yes | No | Yes | 4 | 4 | 16 | |
| | C | Yes | No | Yes | 5 | 2 | 10 | 26 |
| 5e | C | Yes | Yes | No | 5 | 2 | 10 | 10 |
| 5f | B | Yes | Yes | No | 3 | 2 | 6 | |
| | C | No | Yes | No | 2 | 1 | 2 | |
| | C | No | No | No | 0 | 1 | 0 | |
| | D | No | Yes | No | 1 | 2 | 2 | 10 |
| 5g | C | No | No | Yes | 2 | 1 | 2 | |
| | C | No | Yes | No | 2 | 1 | 2 | 4 |
| 5h | C | No | Yes | No | 2 | 2 | 4 | 4 |

The pictures in Fig. 5(a)–5(d) have very little tracking. I consider that they are arranged in the order of ascending skipping content, starting with a score of zero for 5(a) and ending with a maximum value of 26 for 5(d), which is the highest possible for the model used.

The pictures in Fig. 5(e)–5(h) all have obtained high scores for tracking. Those in Fig. 5(g) and 5(h) have the same scores for skipping. Although 5(h) contains lobes 'isolated' by strong tracking, 5(g) contains a pair of lobes 'isolated' by the edge of the picture. Fig. 5(e) and 5(f) have the same score for skipping, despite their very different structure, point reflections across the centre in 5(e) and repetitions in 5(f). The huge score for tracking obtained for 5(e) (in fact, the highest I have been able here to obtain) arises from every arc in all the structural elements being incorporated into a single connected network. The fact that only connecting arcs of value 1 were used suggests that it might be possible to find a $2 \times 2$ specimen of this kind with more tracking.

## IX. CONCLUSIONS

Manuel Barbadillo wrote to me in 1971: 'Could you make the program in such a way that the modification of the structure of the initial picture would be made in several steps (according to an

TABLE 2. NUMERICAL VALUES ASSIGNED TO RELATIONSHIPS THAT PRODUCE SKIPPING MOVEMENT (cf. PART VII).

| | Sufficient relationships | Value | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| A | Mirror image | 4 | | | 3 | | 2 | | 2 |
| B | Repetition | 3 | | | 2 | | 1 | | 1 |
| C | Point reflection through centre of picture | 5 | | | 3 | | 2 | | 0 |
| D | Point reflection through mid-point of common edge | 2 | | | 1 | | 1 | | 0 |
| | Enhancing features: | | | | | | | | |
| P | Same colours | Yes | Yes | Yes | Yes | No | No | No | No |
| Q | Lobe emphasized by strong tracking | Yes | No | Yes | No | Yes | Yes | No | No |
| R | Lobe isolated by edge | Yes | Yes | No | No | Yes | No | Yes | No |

ascending scoring table) so that they would show progressive phases in the interconnection of networks? I don't know what criteria for the table could be, but I believe this would be useful because of the process nature of the art research. It could help us to know more about skipping.'

In this paper, I have presented some of the answers to his question. But the difficulties here that face the computer programmer are mainly of an artistic, rather than of a technical nature. For instance, what is meant by the 'ascending scoring table' is not given in terms of completely closed definitions. Thus, the problem cannot yet be handed to a computer programmer. My hope is that my approach will aid the computer artist in the task of closing definitions of subjectively experienced visual phenomena.

I wish to thank Barbadillo, whose many letters have helped me develop these ideas, and Josephina Mena for translating texts from the Centro de Calculo de la Universidad de Madrid. I am much indebted to Peter Struyken for his clear ideas on visual research [4, 15].

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### *L'art par ordinateur: Un modèle visuel pour les tableaux modulaires de Manuel Barbadillo*

**Résumé**—De 1964 à 1968, Manuel Barbadillo prit pour élément de base de plusieurs de ses tableaux un seul module carré en noir et blanc. Ce module peut engendrer seize formes différentes (ou éléments structuraux) par rotation, par réflexion dans un miroir et par interversion du noir et du blanc. On peut utiliser l'un quelconque de ces éléments structuraux dans n'importe quelle case d'une grille de $4 \times 4$ pour composer un tableau.

Dans des éléments structuraux adjacents, les zones de la même couleur fusionnent et guident librement l'œil sur la surface du tableau. Outre cet aspect du tableau, l'artiste utilisait une forte symétrie, ce qui contribue à la vie de l'œuvre. Les idées impliquées sont très vagues, et l'objet principal de cet article est de montrer comment les programmer sur ordinateur.

En premier lieu, l'auteur décrit en détail les mouvements des yeux en distinguant subjectivement ceux qui consistent à "suivre des yeux" de ceux qui consistent à "sauter d'un point à un autre". Ensuite, ces concepts sont "momentanément fermés" par des définitions qui définissent un modèle visuel subjectif, mais ne peuvent définir les qualités visuelles réelles des tableaux de Barbadillo. Ces définitions permettent l'analyse numérique. Huit tableaux-test de $2 \times 2$ éléments sont présentés avec des résultats numériques qui semblent plausibles. L'auteur espère que l'intégration de ce modèle visuel subjectif à un programme pour ordinateur permettra de produire des tableaux contrôlés par des procédés automatiques de sélection.